Gravity Probe B Project

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Ames Research Center is supporting the development and manufacture of the guide-star telescope detectors of the Gravity Probe B (GPB) Project. GPB is a Stanford University/Lockheed-Martin/Marshall Space Flight Center Physical Science Mission that has called upon Ames Research Center's expertise in cryogenic electronics to help meet the program's launch schedule. The Ames technical contribution has been made over a period of 2 years and is expected to conclude shortly after launch, currently scheduled for March 2000 from Vandenberg Air Force Base.

The GPB fine-motion guide-star tracking system uses a 5.6-inch aperture, all fused-quartz telescope which is attached to a quartz block assembly containing the relativistic-effect sensing gyroscopes. The guide-star telescope rotates about a central axis, thereby providing a constant pointed reference direction to a star fixed on the celestial sphere; this is the distant inertial reference frame. The satellite that contains this assembly will be in a polar orbit about Earth. The precession rate of the sensed gyroscope directional output from the distant inertial reference frame is a possible indication of a general relativistic deviation from that expected by Newtonian gravitational theory. A precession rate is expected to occur at an angular scale of a few arcseconds per year, and it is expected to be measured with an accuracy of about 0.2 milliarcsecond per year. For comparison, the apparent angular diameters of the few nearest stars, visible to all but the largest telescopes as points of light, are less than 10 milliarcseconds.

The first figure is a picture of the quartz telescope with the attached light detectors. The telescope is standing on its base plate. Light enters from above and is reflected into the upper structure, the Knife Edge Divider Assembly, where the beam is divided equally between eight photodiodes. The equality of this division determines the error signal that is sent back to the control circuits which then adjust the spacecraft orientation. Four detectors are needed for complete control; the other four are identical, but redundant. The detectors are at the very top of the figure.

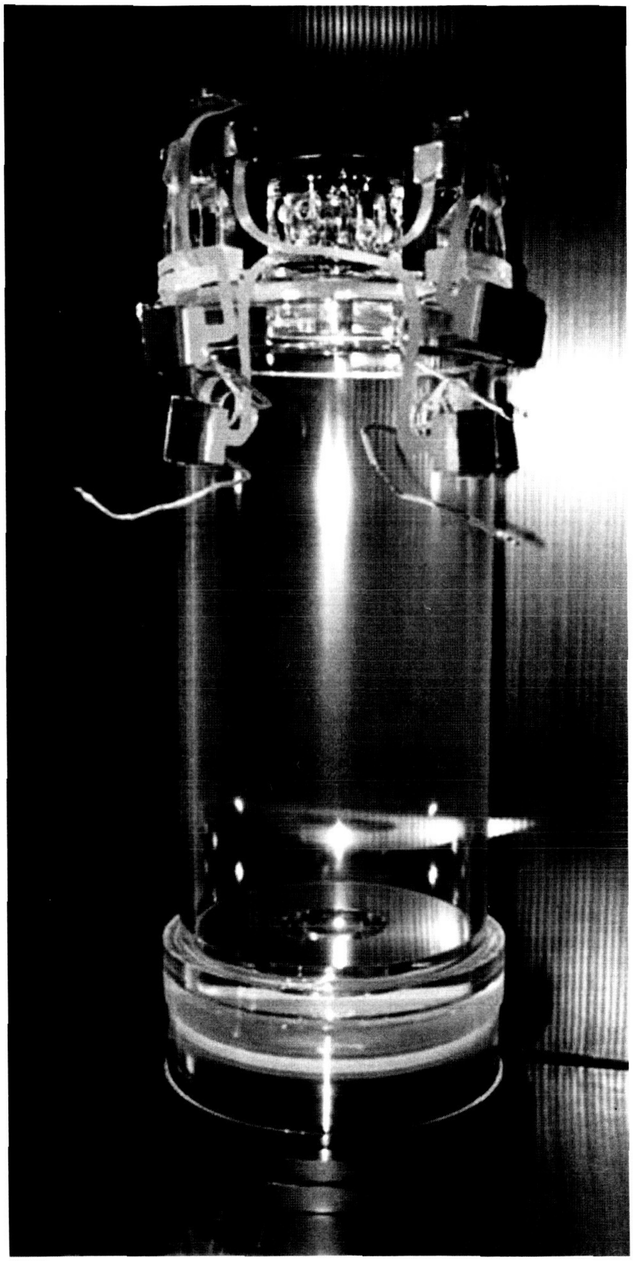

Fig. 1. Gravity Probe B (GPB) 5.6-inch-aperture quartz telescope.

The second figure shows the detector circuit and thermal isolator mounted to its titanium base and flexible cable assembly. Signals are conveyed via flexible printed circuits to connectors that interface the detectors thermally and electrically to a low-thermal-conductivity cable bundle (not shown) which is part of the science instrument assembly.

Ames personnel have been fully matricized into the Telescope Readout Electronics Group of the GPB Project. Significant technical contributions have been made in the areas of cryogenic characterization of electronic components, circuit design, standardization, manufacture, detector circuit acceptance testing, flexible cable design and manufacturing, thermal isolator design and testing, optical calibration, quality assurance, detector package assembly, and acceptance testing.

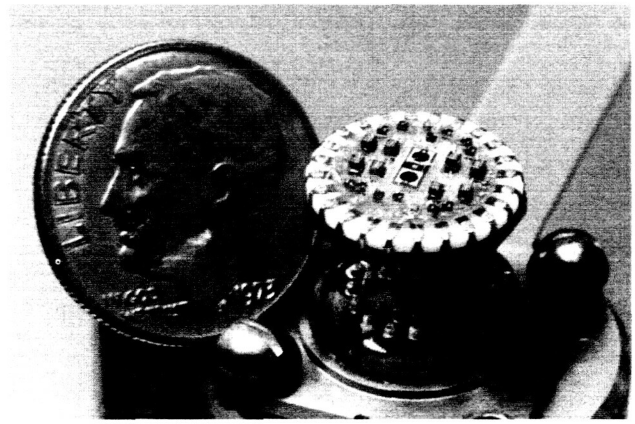

Fig. 2. Guide-star detector circuit and thermal isolator.

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Modeling of Steady Secondary Flows in Pulse Tube Cryocoolers

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A linearized solution for describing steady secondary flows generated by periodic compression and expansion of a gas in a tube has been developed and verified. The small-amplitude series expansion in the inverse Strouhal number at the anelastic limit is applied to the two-dimensional axisymmetric equations for mass, momentum, and energy conservation for an ideal gas. The solution is calculated to higher-order for understanding mass and enthalpy streaming. This work is useful for predicting the streaming losses that are present in pulse tube cryocoolers.

The ordered equations show that the zeroth-, first-, and second-order equations are coupled through the zeroth-order temperature. An analytic solution is obtained in the strong temperature limit where the zeroth-order temperature is constant. The solution shows that periodic heat transfer between the gas and tube, characterized by the complex Nusselt number, is independent of the axial-velocity boundary conditions and the Fourier number. Steady velocities increase linearly for small Valensi numbers and can be of order 1 for a large Valensi number. Decreasing heat transfer between the gas and the tube decreases steady velocities for systems in which nonzero velocity boundary conditions exist at each end of the tube, such as for orifice pulse tubes. For systems in which one end of the tube is closed, such as for basic pulse tubes, increasing heat transfer between the gas and tube decreases steady velocities. The model predicts that a conversion of steady work flow to heat flow occurs whenever temperature, velocity, or phase-angle gradients are present. Additionally, steady enthalpy flows are reduced by heat transfer and are scaled by the Prandtl number times the Valensi number.

Particle velocities from a smoke-wire experiment were compared to model predictions for an orifice pulse-tube configured system (see figure). Mass-streaming and flow reversal between the centerline and diffusion layers of the gas were observed, and velocities were measured. The theory predicted the